

Airway and Thoracic Ultrasound



Martin Demant, MD^a, Paul Koscumb, MD, MS^b,
Elaine Situ-LaCasse, MD^{c,*}

KEYWORDS

- Airway ultrasound • Thoracic ultrasound • Point-of-care ultrasound
- Cricothyroid membrane • Lung ultrasound • Difficult airway management

KEY POINTS

- Airway ultrasound is helpful in the pre-intubation, intra-intubation, and post-intubation phases to increase success of the procedure to optimize patient safety.
- It is important to be systematic when approaching airway ultrasound to not misidentify the son anatomy.
- Thoracic ultrasound is dependent on artifacts, and familiarity with these artifacts will maximize the usefulness of this application in patient care.

INTRODUCTION

Airway and thoracic point-of-care ultrasound (POCUS) applications are relevant for the daily practice of emergency physicians. As anatomically difficult airways can be challenging to predict, POCUS can be used to identify airway pathology, plan for a safer surgical airway technique, and differentiate between tracheal, esophageal, and bronchial intubation.¹ As for thoracic ultrasound, physical examination and chest radiography are less accurate than thoracic POCUS for numerous conditions (eg, pulmonary edema, pneumothorax).²

AIRWAY = ULTRASOUND

Procedural Approach

Probe selection and probe placement

The upper airway and trachea are best evaluated using a high-frequency linear probe. Due to the curvature of the anterior neck, especially over the thyroid cartilage and suprasternal notch, ample ultrasound gel should be used to optimize image quality.

^a Emergency Medicine, Banner University Medical Center Tucson, 1501 North Campbell Avenue, PO Box 245057, Tucson, AZ 85724-5057, USA; ^b Emergency Medicine, University of Texas Medical Branch at Galveston, 301 University Boulevard, Galveston, TX 77555-1173, USA; ^c Emergency Medicine, University of Arizona College of Medicine-Tucson, 1501 North Campbell Avenue, PO Box 245057, Tucson, AZ 85724-5057, USA

* Corresponding author. 1501 North Campbell Avenue, PO Box 245057, Tucson, AZ 85724-5057
E-mail address: esitu@arizona.edu

SHOUT
SHARE **IT**



For views requiring a larger window or if the patient has a larger neck, the curvilinear probe can be used (Fig. 1).

There are 5 probe positions to perform an airway ultrasound examination: (1) suprahyoid view to visualize the tongue in sagittal plane; (2) thyrohyoid view to image the epiglottis in transverse plane; (3) transverse thyroid view to visualize the vocal cords; (4) both the transverse and sagittal views to identify the cricothyroid membrane; and (5) the transverse suprasternal view to visualize the subglottis (Fig. 2).^{3,4}

Clinical Indications

Predicting the difficult airway

POCUS evaluation of the airway has been shown to outperform physical examination and palpation for airway management.³ Of all ultrasound applications evaluating the airway in different neck positions, the hyomental distance (HMD) (Fig. 3) and hyomental distance ratios (HMDRs: HMDR1: flexed/neutral; HMDR2: extended/neutral) measured in neutral, ramped, and extended neck positions are the most accurate (pooled sensitivity 74% and specificity 86%).⁵ This measurement correlates with how much the tongue can be displaced forward and how much the glottic view can be improved with neck positioning. Measurements of the HMD ≤ 5.29 cm (sensitivity 96.7%, specificity 71.6%), the HMDR1 ≤ 1.12 (sensitivity 75%, specificity 76.2%), and the HMDR2 ≤ 1.08 (sensitivity 75%, specificity 85.3%) may predict a difficult airway for endotracheal intubation.⁵⁻⁸ One other measure is the distance from skin to epiglottis (DSE) (Fig. 4), which has data supporting reasonable ability to predict difficult laryngoscopy (sensitivity 82%, specificity 79%).⁸ The DSE normally measures <2.54 cm.^{9,10}

Surgical airway preparation

Due to the time-sensitive and life-saving nature of cricothyrotomy, a successful outcome depends on accurately identifying the cricothyroid membrane (CTM). Marking the neck in the sagittal and transverse plane to identify the CTM before anticipated challenging intubation improves safety, enhances operator confidence, and reduces the time required for the procedure, if necessary.^{11,12}

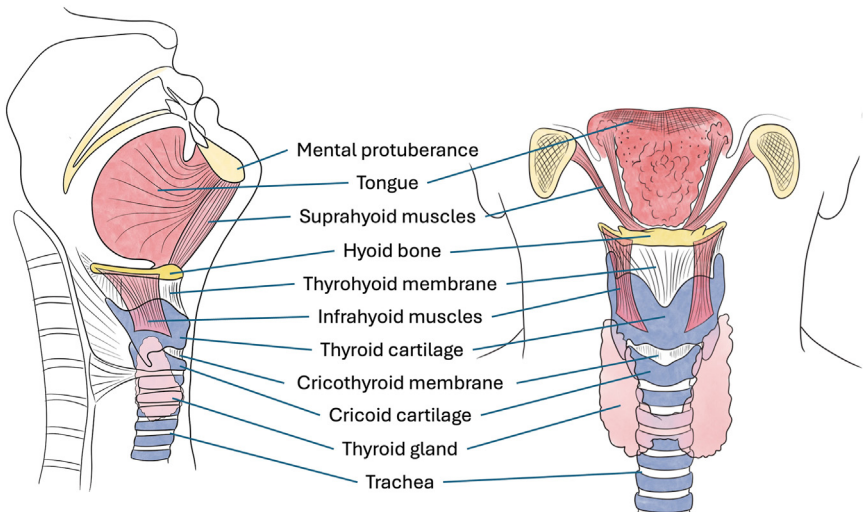


Fig. 1. Lateral and anterior views of the larynx. (Illustrated by Perri Hartenstein, MD)

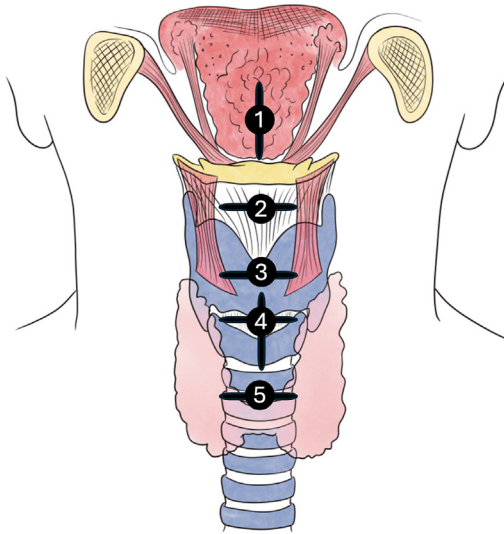


Fig. 2. Airway ultrasound probe placement. (Illustrated by Perri Hartenstein, MD)

The CTM can be located using the thyroid-airline-cricoid-airline (TACA) technique and by identifying the "string-of-pearls" sign.^{3,13} Using the TACA technique, the sonographer scans the anterior neck with a linear probe in the midline transverse plane starting over the upside-down V-shaped thyroid cartilage (**Fig. 5**). Sliding caudally, the cartilage will disappear and be replaced by a prominent hyperechoic line, the air-mucosal interface, between the thyroid and the cricoid cartilage; this is the CTM (**Fig. 6**). For confirmation, the sonographer continues sliding caudally to observe this air-mucosal interface being replaced by the upside-down U-shaped cricoid cartilage.

Alternatively, the "string-of-pearls" sign can be used to identify the CTM by placing a linear probe in the median sagittal plane over the suprasternal notch. The tracheal rings interposed by a thin fibrous membrane will show an alternating hypoechoic and hyperechoic echogenicity representing pearls on a string. The biggest "pearl" is found cranially to the trachea and represents the cricoid cartilage. Moving the probe slightly cranially, the CTM comes into view, bordered by the thyroid cartilage cranially and the cricoid cartilage caudally (**Fig. 7**).



Fig. 3. Tongue. (A) Probe placement. (B) Suprahyoid view with a curvilinear probe. (C) Notated image. *Star*: suprahyoid muscles; *dot*: tongue; *double-headed arrow*: hyomental distance; *dashed arrow*: posterior acoustic shadow of the mentum; *dotted arrow*: posterior acoustic shadow of the hyoid bone.

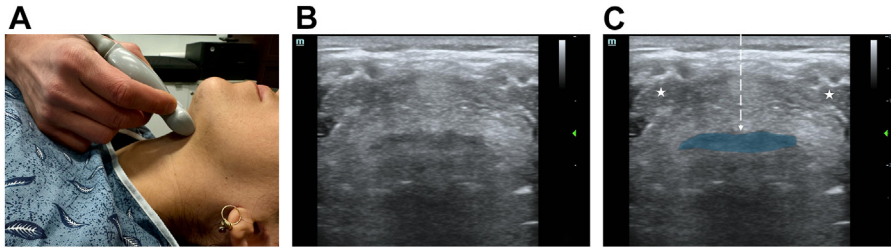


Fig. 4. Epiglottis. (A) Probe placement. (B) Thyroid view with linear probe. (C) Notated image. Stars: infrahyoid muscles; blue: epiglottis; dashed arrow: distance from skin to epiglottis.

Endotracheal tube placement

Confirmation of endotracheal tube (ETT) placement after intubation is essential. Unrecognized esophageal intubation may result in hypoxic brain injury, cardiac arrest, or death. Capnography is the gold standard for ETT placement confirmation, but there are limitations. In 2022, the Project of Universal Management of the Airway established updated guidelines for ETT placement confirmation, recognizing POCUS as one of the means to exclude esophageal intubation.¹⁴ Additionally, the American Heart Association has also supported its use in cardiac arrest since 2015.¹⁵

During upper airway scanning for intubation, the sonographer can locate the air-mucosal interface at the larynx by positioning a linear probe in the midline transverse plane over the suprasternal notch (Fig. 8).¹⁶ The ETT is a plastic tube filled with air, so the sonographic appearance of the larynx remains consistent: a single air-mucosal artifact is observed before, during, and after correct ETT placement. Conversely, in esophageal intubation, a new air-mucosal interface in the esophagus is created, manifesting as a second reverberation artifact on ultrasound. The juxtaposition of the 2 air-mucosal interfaces is termed the “double tract sign” (Fig. 9) and exhibits high accuracy in detecting esophageal intubation (sensitivity 98.7%, specificity 97.1%).¹⁷ It is important to note that approximately 16% of the population has the esophagus positioned behind the larynx, which can limit visibility from the anterior plane. Sliding laterally and rocking posteriorly with the probe increases the chances of seeing a more retrolaryngeal positioned esophagus (see Fig. 9).¹⁸ Some literature has suggested sonographers may have greater difficulty visualizing a tracheal than esophageal intubation; therefore, the authors recommend twisting the ETT to create a motion artifact to enhance visualization.^{19,20}

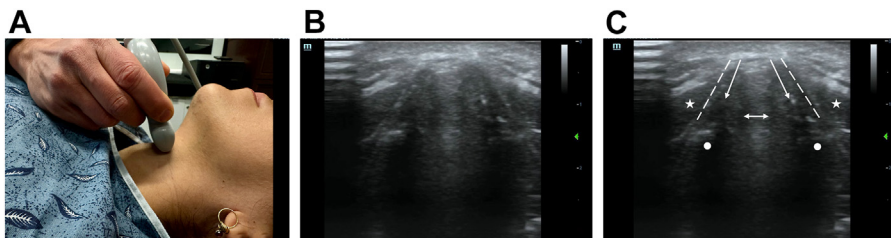


Fig. 5. Vocal cords. (A) Probe placement. (B) Thyroid view with linear probe. (C) Notated image. Stars: infrahyoid muscles; dots: arytenoid cartilages; dashed line: thyroid cartilage; solid arrows: false cords; double-headed arrow: true cords (closed).

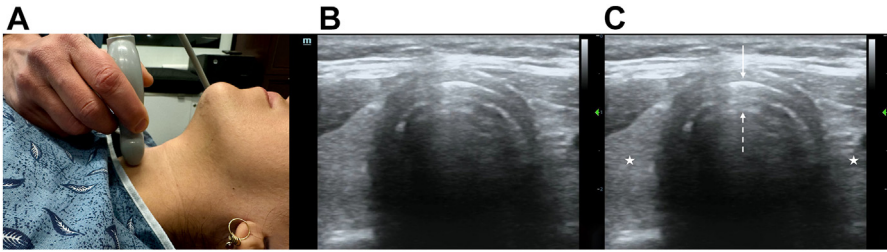


Fig. 6. Cricothyroid membrane in transverse plane. (A) Probe placement. (B) Cricothyroid view with a linear probe. (C) Notated image. *Stars*: thyroid gland; *solid arrow*: cricothyroid membrane; *dashed arrow*: reverberation artifact.

Evaluating for epiglottitis

Epiglottitis has the potential to rapidly progress into airway obstruction, constituting a true airway emergency. While direct visualization of the upper airway remains the gold standard for diagnosis, it poses significant risks, as any mechanical manipulation can provoke a sudden increase in edema with potentially catastrophic consequences. Ultrasound has been proposed as a safer alternative for evaluation.²¹

The physician should acquire the thyrohyoid view to image the epiglottis in transverse plane (see Fig. 4). In patients with epiglottitis, the epiglottic cartilage and pre-epiglottic space are inflamed and thickened. The epiglottis will measure >3 mm in thickness at its greatest diameter, which usually involves the lateral aspects (Fig. 10).

THORACIC ULTRASOUND

Anatomy

In a complete thoracic bedside ultrasound, the sonographer should evaluate 12 zones of the thorax (Fig. 11)²²; although more commonly, sonographers use an abbreviated approach of 4, 6, or 8 lung zones. One should evaluate the superficial structures of the chest wall along with increasing the depth or changing to a lower frequency probe to evaluate deeper lung parenchyma (see Figs. 11 and 12).

Technique

Probe selection

The linear probe provides the best image resolution when imaging superficial structures, while the curvilinear and phased array probes are preferred for deeper pathology or when patient body habitus is a limiting factor. Therefore, the linear probe may

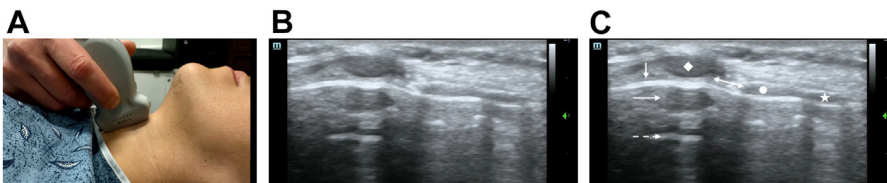


Fig. 7. Cricothyroid membrane in median sagittal plane. (A) Probe placement. (B) Cricothyroid view with linear probe. (C) Notated image. *Diamond*: thyroid cartilage; *dot*: cricoid cartilage; *star*: first tracheal ring; *horizontal arrow*: mirror artifact; *vertical arrow*: air-mucosal interface; *dashed arrow*: reverberation artifact; *double-headed arrow*: cricothyroid membrane.

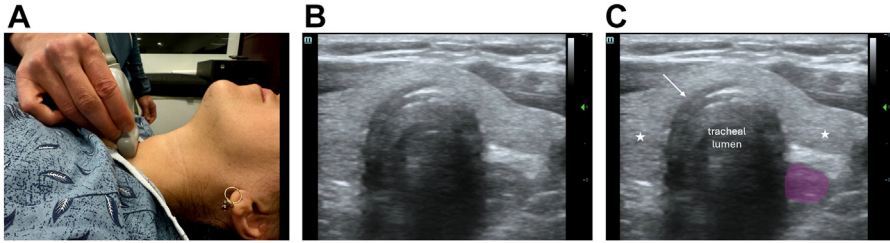


Fig. 8. Subglottis. (A) Probe placement. (B) Suprasternal view with linear probe. (C) Notated image. Arrow: tracheal ring; stars: thyroid gland; purple: esophagus.

be preferential in cases such as in the evaluation of rib fracture or pneumothorax.²³ The curvilinear probe provides greater penetrance into deeper tissue and is a good choice when visualization of deeper tissue such as lung parenchyma or the diaphragm is desired. If lung sliding is not well visualized on the curvilinear probe, some advocate that the linear probe should be utilized to confirm the absence of sliding. However, there is some evidence to suggest that there is no significant difference in diagnostic accuracy between the probes in the diagnosis of pneumothorax.²³ The phased array has the poorest image clarity but has good penetration and depth. Some prefer it due to its smaller footprint, which may allow for better penetration between rib spaces.

Normal Lung

Lung ultrasound can include both pleura and the underlying parenchyma. To perform the pleural examination for pneumothorax, position the probe marker toward the patient's head in the sagittal plane. Adjacent ribs should be aligned on the opposite ends of the ultrasound screen to visualize the pleural line between them. The pleural line under normal circumstances demonstrates a subtle sliding movement with inspiration and expiration, sometimes referred to as “ants marching on a log” (Fig. 13). To evaluate the deeper lung, increase the depth to approximately 18 cm. Under normal circumstances, lung parenchyma is not well visualized due to the presence of gas

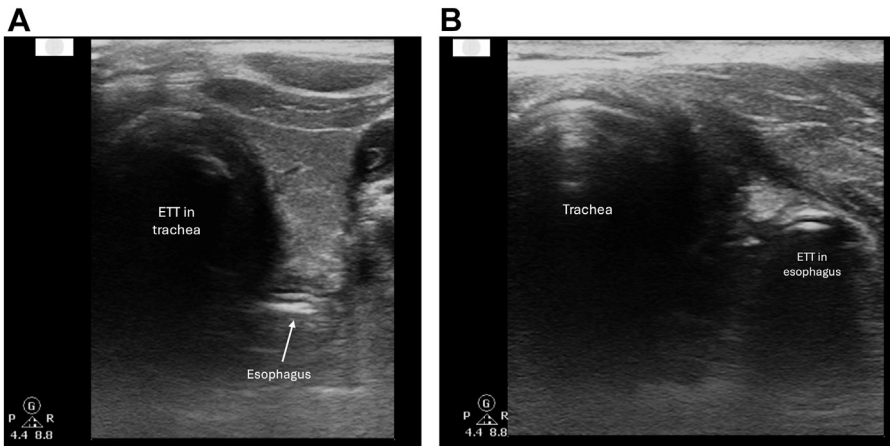


Fig. 9. Suprasternal view of a cadaveric model. (A) Tracheal intubation. (B) Esophageal intubation with a double tract sign. Abbreviation: ETT, endotracheal tube.

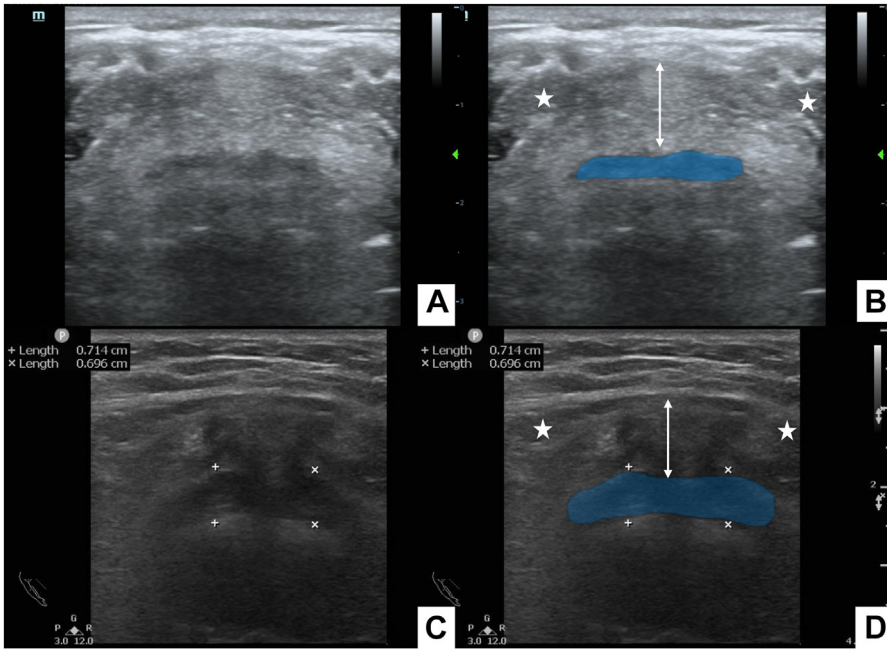


Fig. 10. Epiglottitis. (A, B) Normal epiglottitis. (C, D) Epiglottitis with epiglottis thickness of 7 mm (normal <3 mm) and edematous pre-epiglottic space. Notations—Stars: infrahyoid musculature; blue: epiglottis; double-headed arrows: pre-epiglottic space.

deep to the pleural line. Instead, lung ultrasound evaluates disease that is present at the level of the pleura itself and is largely dependent on artifact that originates at the level of the pleura. Some pathologies, such as pleural effusion or consolidated lung, replace the gas that is located deep to the pleural line with fluid (eg, blood, effusion) that more effectively transmits ultrasound waves. The appearances of many of these pathologies are specific and will be addressed individually.

A-lines

A-lines are hyperechoic lines that repeat at regular intervals beneath the pleural line (Fig. 14) and are seen in the normal lung. Most pathologies involve the accumulation of fluid within the lung parenchyma and, therefore, result in the obliteration of A-lines as the tissue-gas interface is disrupted. A notable exception to this is pneumothorax, where A-lines are preserved, as gas is still present below the pleural line, albeit outside of the normal lung parenchyma.

B-lines

B-lines (also known as comet tails) are vertical reverberation artifacts that cause hyperechoic lines perpendicular to the pleural line which extend to the full depth of the screen (Fig. 15).²⁴ They are a nonspecific finding that represents an increase in density of and/or accumulation of fluid in tissues deep to the pleural line.²⁵ The presence of B-lines has been associated with several pathologic conditions such as infiltrative lung diseases, pulmonary edema, or bacterial or viral pneumonia including COVID-19.^{25,26} The position of the B-lines is often important in distinguishing the pathology. For example, cardiogenic pulmonary edema is typically gravity dependent

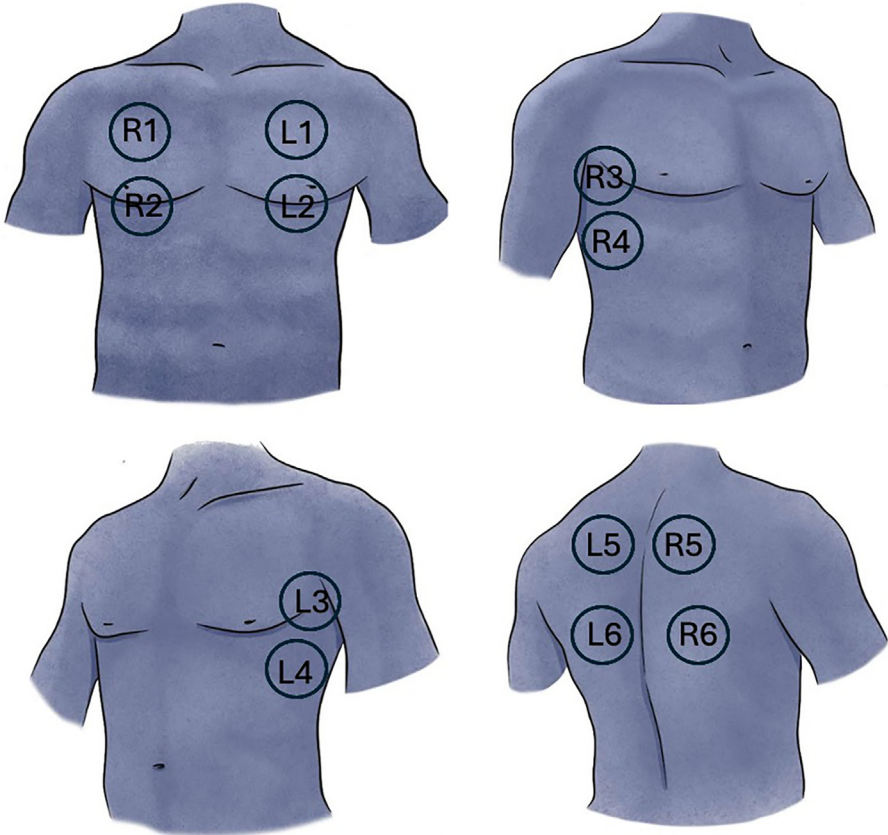


Fig. 11. Thoracic ultrasound probe placement. (Illustrated by Perri Hartenstein, MD)

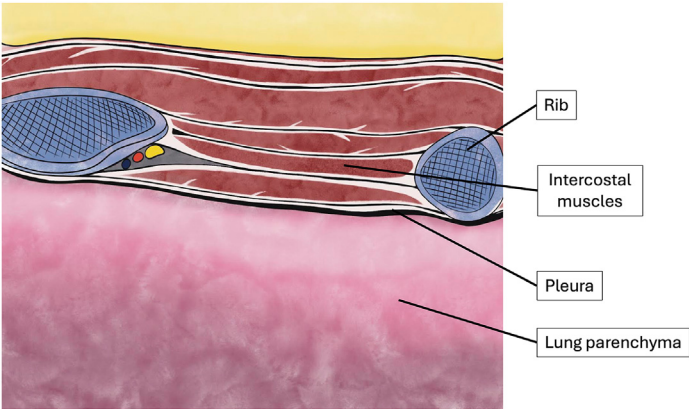


Fig. 12. Cross-sectional view of the chest wall. (Illustrated by Perri Hartenstein, MD)

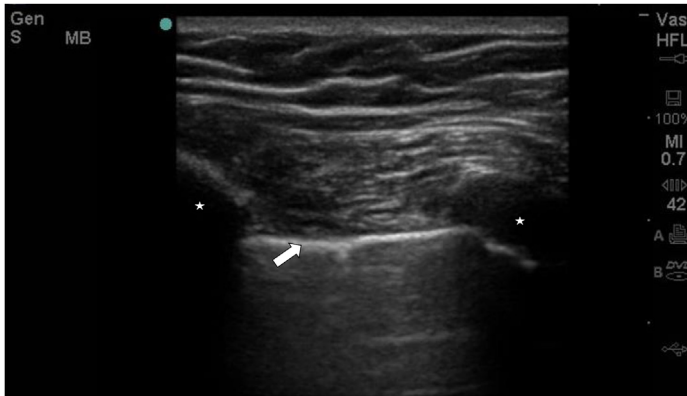


Fig. 13. Normal lung. Notations—stars: adjacent ribs with underlying shadowing; arrow: pleural line.

and is more pronounced in the lung bases in early disease and progresses superiorly as disease progresses.²⁷ In contrast, the B-lines in viral processes, such as COVID-19, are more diffuse.²⁶

Clinical Indications

Pneumothorax

Data show POCUS can decrease the time to diagnosis of pneumothorax, as well as to be more sensitive than chest x-ray for the diagnosis of pneumothorax.^{28,29} When POCUS is being performed to evaluate for a pneumothorax, the lung is evaluated superiorly at the apices in the upright patient or anteriorly in the supine patient as air is gravity dependent; the location that air will be expected to accumulate will vary depending on patient positioning. The primary sonographic sign of pneumothorax is the absence of pleural sliding. However, the absence of lung sliding alone is not 100% specific for pneumothorax. Lung sliding can be absent in patients with main-stem intubation, with history of prior chest tube placement or other thoracic surgery which can result in pleurodesis, with bullous lung disease resulting from pathology

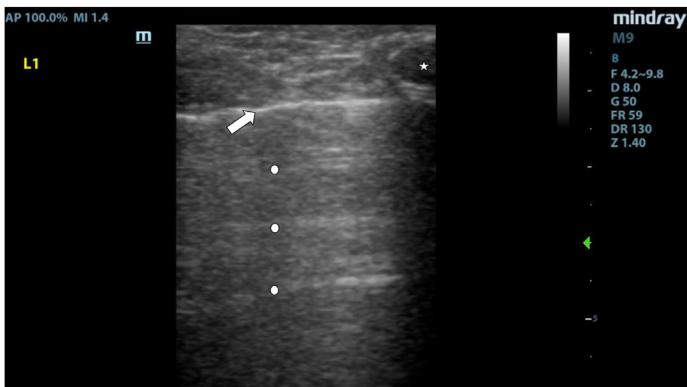


Fig. 14. A-lines. Notations—star: rib with underlying shadowing; arrow: pleural line; dots: repeating A-lines.

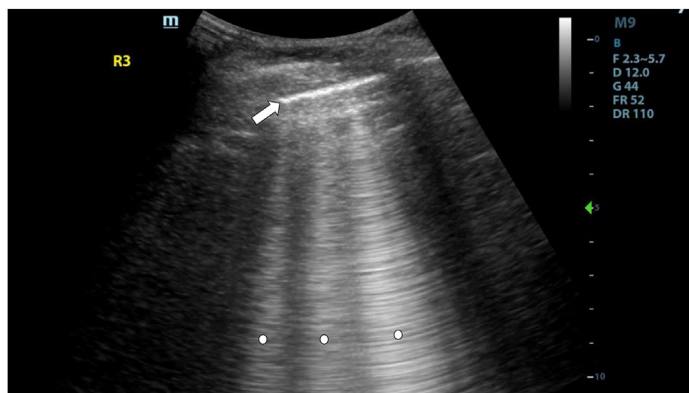


Fig. 15. B-lines. Notations—arrow: pleural line; dots: multiple adjacent B-lines within the same rib space (3 or more is abnormal).

such as chronic obstructive pulmonary disease, and in other clinical conditions.³⁰ One clinical pearl to remember is that B-lines originate from tissues deep to the pleurae. Therefore, their presence effectively rules out the presence of a pneumothorax, even when lung sliding is absent since there cannot be air interposing between the pleurae in this situation. Other findings that may suggest pneumothorax include a lung point, which is the direct visualization of the beginning or end of a pneumothorax. Pleural sliding will be observed on one side of the lung point and absent on the other. Lung points are less frequently visualized but are highly specific for pneumothorax (approaching 99%–100%).^{31,32}

M-mode can also be utilized to aid in diagnosis. A “seashore sign” describes the static appearance of the structures superficial to the pleural line and a granular appearance deep to the pleural line due to the interference from lung motion (Fig. 16). This is seen in the absence of a pneumothorax. A “barcode sign” describes static appearance of all structures due to the absence of lung motion resulting in straight lines across the image (Fig. 17). While M-mode is not essential in the diagnosis of pneumothorax, it has been suggested to increase the accuracy of the diagnosis in novice or inexperienced sonographers. This benefit was not seen in more experienced clinicians.³³

Bacterial pneumonia

B-lines are often the first sonographic sign of pneumonia.³⁴ In the setting of pneumonia, they represent inflammation and the subsequent accumulation of fluid within alveolar spaces. B-lines are nonspecific findings and should be put into clinical context. Typical pneumonia often occurs in a lobar distribution and as such B-lines may be present focally in a lung field that would correspond with a single lung lobe. Bacterial pneumonia may also be atypical and be diffusely distributed and in these settings may be difficult to differentiate from viral pneumonia. The presence of sub-pleural consolidations may help in distinguishing B-lines caused by infectious or inflammatory processes such as pneumonia from B-lines related to pulmonary edema or acute respiratory distress syndrome.³⁵

As disease progresses, air is displaced from enough of the lung parenchyma that a consolidated lung may become readily visible (Fig. 18). This consolidated lung has an echotexture that is very similar to that of the liver and may be analogous to the hepaticization that occurs histologically with lobar pneumonia. Hyperechoic spots within the

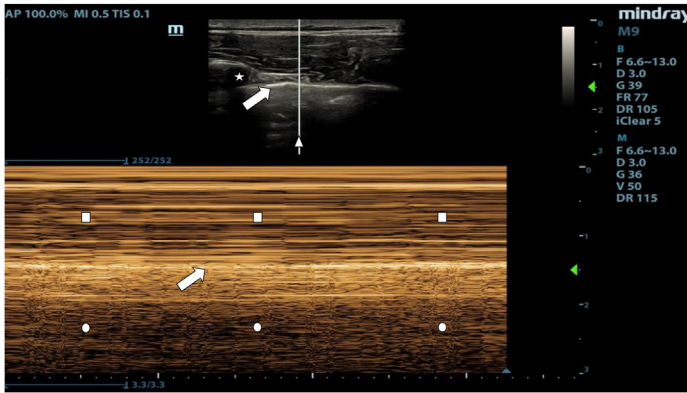


Fig. 16. Seashore Sign. Upper image: normal ultrasound projection; lower image: M-mode ultrasound projection generated by projection through the line denoted by *triangle*. Notations—*arrows*: pleural line; *star*: rib with underlying shadowing; *squares*: linear projections caused by static position of structures superficial to pleural line; *dots*: blurry/hazy appearance of structures deep to pleural line caused by interference from pleural motion.

consolidated lung represent air within the bronchi are termed “air bronchograms.” These may also be seen with atelectasis; however, air bronchograms that move with respiration, termed “dynamic air bronchograms,” are highly specific for pneumonia.³⁶

Viral pneumonia

Viral pneumonia has a sonographic appearance similar to the early stages of bacterial pneumonia, namely that of B-line predominance, pleural line irregularities, and the presence of subpleural consolidations (Fig. 19).³⁴ However, viral pneumonia typically presents with a more diffusely distributed B-line pattern rather than the lobar pattern seen in bacterial pneumonia. Of note, atypical bacterial pneumonia can present like

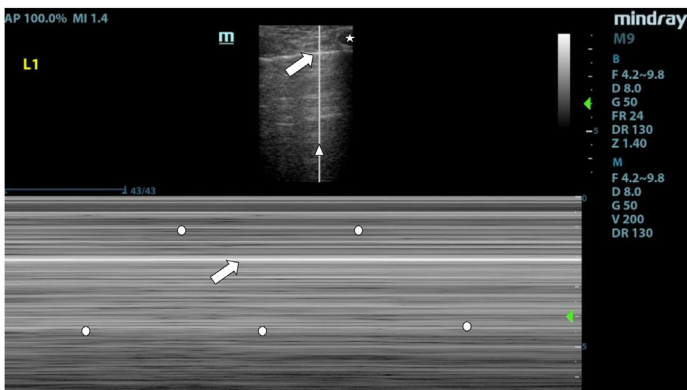


Fig. 17. Barcode Sign. Upper image: normal ultrasound projection; lower image: M-mode ultrasound projection generated by projection through the line denoted by *triangle*. Notations—*arrows*: pleural line; *star*: rib with underlying shadowing; *dots*: linear projections both superior and deep to the pleural line caused by lack of interference from pleural motion.

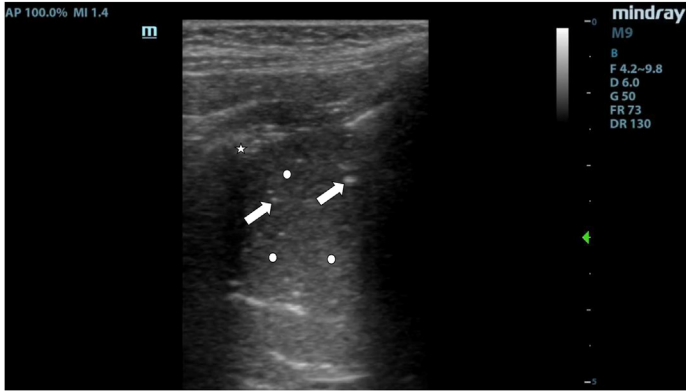


Fig. 18. Consolidation suggestive of bacterial pneumonia. Notations—star: rib with underlying shadowing; dots: consolidated lung deep to the ribs which appears as a solid organ similar in echotexture to liver; arrows: air bronchograms (hyperechoic foci of trapped air/gas).

viral pneumonia. Lung ultrasound became a common imaging modality for the evaluation of pneumonia caused by COVID-19 due to its superior sensitivity when compared to x-ray, its ability to be performed at the bedside without unnecessary exposure of ancillary staff (eg, radiology staff/technicians), lack of ionizing radiation, and its reproducibility across multiple examinations.³⁷ COVID-19 pneumonia was found to be predominant in the posterior and inferior lung fields and a more comprehensive approach to scanning is recommended in these patients. Large lobar consolidations can be seen in viral pneumonia, including COVID-19, however, they typically appear late in the course and typically represent advanced disease. Findings of lobar pneumonia early in the course of the disease should raise suspicion of a diagnosis other than COVID-19. This may be a finding of superimposed bacterial pneumonia.^{38–40}



Fig. 19. Viral pneumonia, including COVID-19 pneumonia. Notations—stars: subpleural consolidations with associated pleural line discontinuities; arrows: B-lines originating from these consolidations and extending into the far field; dots: normal A-lines in unaffected adjacent lung.



Fig. 20. Jellyfish Sign. Notations—*dots*: large pleural effusion with resultant atelectasis/compression of lung; *star*: tendril-like extension of compressed lung tissue; *triangles*: diaphragm; *squares*: liver; *arrow*: air bronchogram within atelectatic lung.

Pleural effusion

Lung ultrasound can also identify complications of pneumonia such as effusion or empyema. Lung ultrasound can detect scant quantities of pleural fluid, as little as 5 mL, whereas in upright chest x-ray the lower limit of detection of pleural fluid is approximately 150 mL, and supine x-ray fares even worse. Fluid collections may be simple or complex. Most simple effusions appear as black hypoechoic regions in the most gravity-dependent regions immediately superior to the diaphragm.^{41,42} As they increase in size, they may be present more superiorly. Moderately sized or large effusions may compress lung parenchyma. The resultant atelectatic lung may be visualized freely floating within the effusion, which is referred to as the “jellyfish sign” due to the thin, tendril-like appearance of the lung (Fig. 20). Free movement of this tissue suggests that the effusion is simple in nature; complex effusions with debris or septations are more likely to limit the movement of the atelectatic lung. Complex pleural effusions are more likely to have a more hyperechoic appearance than the



Fig. 21. Spine Sign. Notations—*triangles*: diaphragm; *squares*: liver; *arrows*: repeated vertebral bodies visualized superior to the diaphragm due to the presence of pleural effusion.

anechoic appearance of simple fluid and are more likely to have mixed textures that may represent purulence or debris.⁴³

The “spine sign” is also associated with the presence of pleural effusion. Normally, the thoracic spine is not visualized sonographically as the air-filled lung interposes between the vertebrae and the probe. When the ultrasound probe is positioned at the lung base, the vertebrae should be visible inferior to the diaphragm and be obscured superior to the diaphragm. However, effusions transmit ultrasound waves and permit the visualization of structures posterior to them and, as such, the thoracic spine will continue to be visible superior to the diaphragm (Fig. 21).⁴⁴

Lung ultrasound protocols	
Lung Protocol	Description
Bedside Lung Ultrasound in Emergency (BLUE) ²⁰	Identifies the etiology of acute respiratory failure (pulmonary edema, pulmonary embolism, pneumonia, chronic obstructive pulmonary disease, asthma, or pneumothorax)
Fluid Administration Limited by Lung Sonography (FALLS) ⁴⁵	Utilizes lung ultrasound in conjunction with basic cardiac sonography (identification of effusion or right heart strain to suggest pulmonary embolism) to identify the likely etiology in cases of shock of unknown origin
Rapid Ultrasound for Shock and Hypotension (RUSH) ⁴⁶	Utilizes lung ultrasound to evaluate for hemothorax and pneumothorax in conjunction with the Focused Assessment with Sonography in Trauma (FAST) examination and cardiac ultrasound to determine the etiology of shock

SUMMARY

Both airway and thoracic POCUS can assist in diagnosis, treatment decisions, and procedural preparation and/or guidance. The key to becoming more comfortable in airway ultrasound is to be systematic and become familiar with the structures sonographically. Airway ultrasound and thoracic ultrasound can be used in conjunction to prepare for endotracheal intubation or planning for a surgical airway. Uncommon, but life-threatening diagnoses, such as epiglottitis, can be diagnosed with POCUS to guide airway management.

Thoracic ultrasound is superior to chest x-ray in numerous instances, and it is easy, quick, and safe to perform. The thoracic ultrasound examination can be repeated without added radiation to the patient. It can guide management, monitor disease evolution, and be utilized in performing a thoracentesis. This will be discussed in a later article.

CLINICS CARE POINTS

- The CTM should be identified and marked in any patient with a predicted anatomically or physiologically difficult airway.
- Sonographic evaluation of the epiglottis and pre-epiglottic space is a non-invasive means to assess the patient’s airway as the physician is preparing for endotracheal intubation.
- Intubation can be assessed with ultrasound with a high degree of accuracy.

- Thoracic ultrasound is based on artifacts. Becoming comfortable with the most common artifacts can maximize the clinical application of thoracic ultrasound findings.
- Thoracic ultrasound can diagnose pathology of the pleura, extrapleural space, parenchyma, and small airways. It can also monitor the progression of certain pulmonary diseases over time without added radiation exposure to the patient.

DISCLOSURE

The authors have nothing to disclose.

REFERENCES

1. You-Ten KE, Siddiqui N, Teoh WH, et al. Point-of-care ultrasound (POCUS) of the upper airway. *Can J Anaesth* 2018;65(4):473–84.
2. Hendin A, Koenig S, Millington SJ. Better with ultrasound: thoracic ultrasound. *Chest* 2020;158(5):2082–9.
3. Lin J, Bellinger R, Shedd A, et al. Point-of-care ultrasound in airway evaluation and management: a comprehensive review. *Diagnostics (Basel)* 2023;13(9):1541.
4. Gottlieb M, O'Brien JR, Ferrigno N, et al. Point-of-care ultrasound for airway management in the emergency and critical care setting. *Clin Exp Emerg Med* 2023. <https://doi.org/10.15441/ceem.23.094>.
5. Bhargava V, Rockwell NA, Tawfik D, et al. Prediction of difficult laryngoscopy using ultrasound: a systematic review and meta-Analysis. *Crit Care Med* 2023; 51(1):117–26.
6. Petrișor C, Trancă S, Szabo R, et al. Clinical versus ultrasound measurements of hyomental distance ratio for the prediction of difficult airway in patients with and without morbid obesity. *Diagnostics (Basel)* 2020;10(3):140.
7. Wu H, Wang H. Diagnostic efficacy and clinical value of ultrasonography in difficult airway assessment: based on a prospective cohort study. *Contrast Media Mol Imaging* 2022;2022:4706438.
8. Rana S, Verma V, Bhandari S, et al. Point-of-care ultrasound in the airway assessment: A correlation of ultrasonography-guided parameters to the Cormack-Lehane Classification. *Saudi J Anaesth* 2018;12(2):292–6.
9. Carsetti A, Sorbello M, Adrario E, et al. Airway ultrasound as predictor of difficult direct laryngoscopy: a systematic review and meta-analysis. *Anesth Analg* 2022; 134(4):740–50.
10. Falcetta S, Cavallo S, Gabbanelli V, et al. Evaluation of two neck ultrasound measurements as predictors of difficult direct laryngoscopy: A prospective observational study. *Eur J Anaesthesiol* 2018;35(8):605–12.
11. Adhikari S, Situ-LaCasse E, Acuña J, et al. Integration of pre-intubation ultrasound into airway management course: a novel training program. *Indian J Crit Care Med* 2020;24(3):179–83.
12. Arthurs L, Erdelyi S, Kim DJ. The effect of patient positioning on ultrasound landmarking for cricothyrotomy. *Can J Anaesth* 2021 Jan;68(1):24–9.
13. Kristensen MS, Teoh WH, Rudolph SS, et al. Structured approach to ultrasound-guided identification of the cricothyroid membrane: a randomized comparison with the palpation method in the morbidly obese. *Br J Anaesth* 2015;114(6):1003–4.

14. Chrimes N, Higgs A, Hagberg CA, et al. Preventing unrecognized oesophageal intubation: a consensus guideline from the Project for Universal Management of Airways and International Airway Societies. *Anaesthesia* 2022;77(12):1395–415.
15. Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: adult advanced cardiovascular life support: 2015 american heart association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2015;132(18 Suppl 2):S444–64.
16. Lonchena T, So S, Ibinson J, et al. Optimization of ultrasound transducer positioning for endotracheal tube placement confirmation in cadaveric model. *J Ultrasound Med* 2017;36(2):279–84.
17. Gottlieb M, Holladay D, Peksa GD. Ultrasonography for the confirmation of endotracheal tube intubation: a systematic review and meta-analysis. *Ann Emerg Med* 2018 Dec;72(6):627–36.
18. Gottlieb M, Bailitz JM, Christian E, et al. Accuracy of a novel ultrasound technique for confirmation of endotracheal intubation by expert and novice emergency physicians. *West J Emerg Med* 2014;15(7):834–9.
19. Gottlieb M, Burns K, Holladay D, et al. Impact of endotracheal tube twisting on the diagnostic accuracy of ultrasound for intubation confirmation. *Am J Emerg Med* 2020;38(7):1332–4.
20. Gottlieb M, Patel D, Sundaram T. Comparison of endotracheal tube location on ultrasound accuracy, time, and confidence. *Am J Emerg Med* 2022;62:127–8.
21. Hung TY, Li S, Chen PS, et al. Bedside ultrasonography as a safe and effective tool to diagnose acute epiglottitis. *Am J Emerg Med* 2011;29(3):359, e3593.
22. Lichtenstein DA, Mezière GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008;134(1):117–25.
23. Griffith JF, Rainer TH, Ching AS, et al. Sonography compared with radiography in revealing acute rib fracture. *Am J Roentgenol* 1999;173(6):1603–9.
24. Ketelaars R, Gülpinar E, Roes T, et al. Which ultrasound transducer type is best for diagnosing pneumothorax? *Crit Ultrasound J* 2018;10(1):27.
25. Lichtenstein D, Mézière G, Biderman P, et al. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997;156(5):1640–6.
26. Gil-Rodríguez J, Pérez de Rojas J, Aranda-Laserna P, et al. Ultrasound findings of lung ultrasonography in COVID-19: A systematic review. *Eur J Radiol* 2022;148:110156.
27. Soldati G, Demi M. The use of lung ultrasound images for the differential diagnosis of pulmonary and cardiac interstitial pathology. *J Ultrasound* 2017;20(2):91–6.
28. Zhang M, Liu ZH, Yang JX, et al. Rapid detection of pneumothorax by ultrasonography in patients with multiple trauma. *Crit Care* 2006;10(4):R112.
29. Ding W, Shen Y, Yang J, et al. Diagnosis of pneumothorax by radiography and ultrasonography: a meta-analysis. *Chest* 2011;140(4):859–66.
30. Lichtenstein DA. Lung ultrasound in the critically ill. *Ann Intensive Care* 2014;4(1):1.
31. Santos-Silva J, Lichtenstein D, Tuinman PR, et al. The lung point, still a sign specific to pneumothorax. *Intensive Care Med* 2019;45(9):1327–8.
32. Lichtenstein D, Mezière G, Biderman P, et al. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive Care Med* 2000;26(10):1434–40.
33. Avila J, Smith B, Mead T, et al. Does the Addition of M-Mode to B-Mode Ultrasound Increase the Accuracy of Identification of Lung Sliding in Traumatic Pneumothoraces? *J Ultrasound Med* 2018;37(11):2681–7.

34. Kameda T, Mizuma Y, Taniguchi H, et al. Point-of-care lung ultrasound for the assessment of pneumonia: a narrative review in the COVID-19 era. *J Med Ultrason* (2011) 2021;48(1):31–43.
35. Parlamento S, Copetti R, Di Bartolomeo S. Evaluation of lung ultrasound for the diagnosis of pneumonia in the ED. *Am J Emerg Med* 2009;27(4):379–84.
36. Lichtenstein D, Mezière G, Seitz J. The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. *Chest* 2009;135(6):1421–5.
37. Pivetta E, Goffi A, Tizzani M, et al. Lung Ultrasonography for the Diagnosis of SARS-CoV-2 Pneumonia in the Emergency Department. *Ann Emerg Med* 2021;77(4):385–94.
38. Castela J, Graziani D, Soriano JB, et al. Findings and prognostic value of lung ultrasound in COVID-19 Pneumonia. *J Ultrasound Med* 2021;40(7):1315–24.
39. Volpicelli G, Lamorte A, Villén T. What's new in lung ultrasound during the COVID-19 pandemic. *Intensive Care Med* 2020;46(7):1445–8.
40. Tan G, Lian X, Zhu Z, et al. Use of Lung Ultrasound to Differentiate Coronavirus Disease 2019 (COVID-19) Pneumonia From Community-Acquired Pneumonia. *Ultrasound Med Biol* 2020;46(10):2651–8.
41. Kocijancic I, Kocijancic K, Cufer T. Imaging of pleural fluid in healthy individuals. *Clin Radiol* 2004;59(9):826–9.
42. Collins JD, Burwell D, Furmanski S, et al. Minimal detectable pleural effusions. A roentgen pathology model. *Radiology* 1972;105(1):51–3.
43. Bhoil R, Ahluwalia A, Chopra R, et al. Signs and lines in lung ultrasound. *J Ultrason* 2021;21(86):e225–33.
44. Dickman E, Terentiev V, Likourezos A, et al. Extension of the Thoracic Spine Sign: A New Sonographic Marker of Pleural Effusion. *J Ultrasound Med* 2015;34(9):1555–61.
45. Lichtenstein D. FALLS-protocol: lung ultrasound in hemodynamic assessment of shock. *Heart Lung Vessel* 2013;5(3):142–7.
46. Perera P, Mailhot T, Riley D, et al. The RUSH exam: Rapid Ultrasound in SHock in the evaluation of the critically ill. *Emerg Med Clin North Am* 2010;28(1):29–vii.